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LOW OVERHEAD TRANSMIT CHANNEL ESTIMATION

FIELD OF THE INVENTION

The invention relates generally to wireless communications and, more particularly, to
5 transmit channel estimation in wireless communications.

BACKGROUND OF THE INVENTION

For some types of wireless communication systems, it is advantageous or necessary
that the transmitter know the channel characteristics prior to transmitting. As an example,
consider multiple input multiple output (MIMO) communication systems. In a MIMO
10 system, each station has multiple transceivers. A station is capable of either transmitting
multiple signals simultaneously via different antennas, or receiving multiple signals
simultaneously via different antennas. In these systems, it may be advantageous to adjust the
powers or other parameters of the different transmitted signals based upon the characteristics
of the transmission channels. To do this, the transmitting station must have knowledge of
15 the channels' characteristics.

One way to get this knowledge is to transmit known measurement signals to the
receiver, perform channel estimates at the receiver based upon the received signals, and then
send the channel estimate information back to the original transmitting station.

This solution is costly in terms of data transmission efficiency. Transmitting the channel estimate back to the originator is an overhead that subtracts from the data transmission time, as is the need to send a known signal to the receiver. In addition, the time delays involved in doing this may make the channel information “stale” or out of date by the time it is obtained at the originator.

It is therefore desirable to reduce the aforementioned overhead associated with conventional transmit channel estimation.

Exemplary embodiments of the present invention can reduce overhead by estimating a relationship between the transmit and receive channels associated with a transceiver, and then estimating the transceiver’s transmit channel at any time based on the aforementioned relationship.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 diagrammatically illustrates exemplary wireless communication systems in which exemplary embodiments of the present invention can be incorporated.

FIGURE 2 diagrammatically illustrates exemplary MIMO wireless communication systems in which exemplary embodiments of the present invention can be incorporated.

FIGURE 3 diagrammatically illustrates exemplary embodiments of a transmit channel estimation apparatus according to the invention.

FIGURE 4 illustrates exemplary calibration operations which can be performed by transmit channel estimators such as illustrated in FIGURE 3.

DETAILED DESCRIPTION

In some wireless communication systems, for example systems that utilize orthogonal frequency division multiplexing (OFDM), data is transmitted on multiple frequencies, so the data transmission channel actually includes multiple constituent channels, and a channel estimate of the data transmission channel actually includes multiple constituent channel estimates which respectively correspond to the aforementioned multiple constituent channels. The term “channel” as used herein should be understood to comprehend the aforementioned type of channel that includes multiple constituent channels, and the term “channel estimate” as used herein should be understood to comprehend the aforementioned type of channel estimate that includes multiple constituent channel estimates.

Exemplary embodiments of the invention implement a two-step solution for low overhead transmit channel estimation. The first step is a calibration procedure that measures a relationship between the forward (transmit) path channel (e.g., from transceiver 1 to transceiver 2) and the reverse (receive) path channel (e.g., from transceiver 2 to transceiver 1). The second step is to use the relationship obtained from the calibration procedure, together with a channel measurement obtained for the reverse path channel, to compute a forward path channel. The calibration step need only be done once, e.g., prior to transmission of any data. Once this has been done, the forward path channels can be

computed based on the calibration step result and current information about the reverse path (receive) channels. This eliminates much of the aforementioned overhead.

In many wireless communications systems, a mechanism is provided in the communication protocol to measure the transmission channel. For example, the wireless local area network (LAN) standard IEEE 802.11a defines a protocol for wireless communications between multiple transceivers using Orthogonal Frequency Division Multiplexing (OFDM). That standard includes a channel measurement transmission with the transmission of the data packets. The measurement of the channel, also called channel estimation, is required for the proper decoding of data at the receiver. In the case of OFDM, the channel is characterized by a set of complex gains at each data transmission frequency (i.e. each OFDM tone). The channel estimate for OFDM is a set of complex numbers, each an estimate of the complex gain of the channel at a given frequency.

FIGURE 1 illustrates the communication scenario between two transceivers. Each transceiver is composed of transmit hardware, receive hardware, a transmit-receive antenna switch, and an antenna. The figure also shows the forward or transmit transmission channel for transceiver 1 and the reverse or receive transmission channel for transceiver 1. The forward channel is the outgoing or transmit channel, whereas the reverse channel is the inbound or receive channel. In the figure, the designation of forward and reverse channels is relative to transceiver 1. Not shown in the figure are the forward and reverse channels for transceiver 2. The forward channel for transceiver 2 is the reverse channel for transceiver 1,

and vice-versa. Also, the reverse channel for transceiver 2 is the forward channel for transceiver 1. Exemplary embodiments of this invention convert the reverse path channel estimate into a forward path channel estimate by multiplication of each of the complex gains by correction factors (complex numbers). This is done without further channel estimates or communication between transceiver 1 and transceiver 2, thus reducing overhead and delays.

The channels are mathematically modeled by their complex gain. Transceiver 1 has a forward path channel complex gain given by

$$c_{12} = g_{t1} \cdot h \cdot g_{r2} ,$$

where c_{12} is the forward path complex gain (from transceiver 1 to transceiver 2, designated by the subscript 12), g_{t1} is the transmitter complex gain of transceiver 1, h is the spatial channel gain, and g_{r2} is the receiver complex gain of transceiver 2. The transmit and receiver gains include the relevant portions of the transmit-receive switch and the antenna. Similarly, transceiver 1 has a reverse path complex gain given by

$$c_{21} = g_{t2} \cdot h \cdot g_{r1} ,$$

where c_{21} is the reverse path complex gain (from transceiver 2 to transceiver 1), g_{t2} is the complex gain of transmitter 2, and g_{r1} is the complex gain of receiver 1.

The first step of this invention is a calibration step that measures the forward and reverse channels and computes correction factors. The procedure begins with transceiver 1 sending a channel estimation transmission to transceiver 2. Transceiver 2 receives the transmission and immediately sends a channel estimation transmission back to transceiver 1.

This latter transmission is sent promptly to prevent the spatial channel from appreciably changing (decorrelating) during the time between the two transmissions.

Immediately after receiving the channel estimation transmissions, each transceiver computes an estimate of the channel. Specifically, transceiver 1 computes an estimate of c_{21} given by

$$\hat{c}_{21} = x_{r1} / x_{t2},$$

where the hat (^) designates an estimate. This is computed from the received signal x_{r1} , with the channel estimation transmission x_{t2} known a-priori (i.e. specified in the signaling standard). Similarly, transceiver 2 computes an estimate of c_{12} given by

$$\hat{c}_{12} = x_{r2} / x_{t1},$$

with x_{r2} the received signal and x_{t1} a specified transmitted signal.

Transceivers 1 and 2 then exchange channel estimates, so that both transceiver have both \hat{c}_{12} and \hat{c}_{21} available. Transceiver 1 then computes reverse to forward correction factors f_1 given by

$$f_1 = \hat{c}_{12} / \hat{c}_{21}.$$

To the extent that the estimates are accurate representations of the actual channels, these are approximately

$$f_1 \approx \frac{c_{12}}{c_{21}} = \frac{g_{t1} \cdot h \cdot g_{r2}}{g_{t2} \cdot h \cdot g_{r1}} = \frac{g_{t1} \cdot g_{r2}}{g_{t2} \cdot g_{r1}}.$$

Normally the estimates are very good and the approximation is close to exact. Similarly, transceiver 2 computes correction factors f_2 given by

$$f_2 = \hat{c}_{21} / \hat{c}_{12} ,$$

which are approximately

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$$f_2 \approx \frac{g_{t2} \cdot g_{r1}}{g_{t1} \cdot g_{r2}} .$$

The computation of these correction factors completes the calibration step. The correction factors are the information needed to convert a reverse channel estimate into a forward channel estimate. They are stored in the transceiver for use later.

10 Note that the correction factors f are not functions of the spatial channel h , but instead are functions of the transmitter and receiver gains. These gains are significantly more stable than the spatial channel, in that they remain constant over much longer time intervals. Hence, the calibration procedure needs to be performed much less frequently than the reverse channel estimation procedure, which must be performed often enough to track changes in the spatial channel.

15 In a second step of this invention, a transceiver converts reverse channel estimates into forward channel estimates by multiplying the reverse channel estimates by the correction factors f_1 or f_2 . For example, if transceiver 1 receives a transmission from transceiver 2, it routinely computes new reverse channel estimates \hat{c}_{21} based upon its

received signal. In accordance with this invention, it converts the reverse channel estimates into forward channel estimates by multiplying by f_1 , via

$$\hat{c}_{12} = f_1 \cdot \hat{c}_{21}.$$

This procedure, which multiplies a reverse channel estimate by a complex number, is a much simpler procedure for obtaining an estimate of the forward channel than the alternative procedure that consists of sending a channel estimation transmission to transceiver 2 and then having transceiver 2 send the channel estimates back to the originating transceiver. A second advantage of this procedure is that it is faster than the alternative procedure also, and so provides an estimate with less latency than the alternative. A third advantage is that it eliminates the overhead transmissions of the alternative procedure, and thus increases the data transmission efficiency of the entire system.

In many cases, the availability of the correction factors will eliminate the need for overhead transmissions for the purpose of measuring and communicating the transmit channel. However, it is possible that a transceiver may have data to transmit to another transceiver but has not received any data transmissions from the target transceiver and hence has not computed a recent receive channel estimate. In these cases, the transmitting transceiver can ask the target receive transceiver to send a data packet upon which it can compute the receive channel estimate. In computer jargon, it *pings* the target transceiver. Even in these cases, the execution of the ping is much quicker than asking the receiver to compute a channel estimate and transmit the results.

In some systems, power adjustments to the transmit chains are made based upon the characteristics of the transmit channels. In the case of a multiple input multiple output (MIMO) system, there are multiple channels in operation simultaneously. For that case, multiple calibrations and multiple correction factors will be needed. The calibration operation will be the same in the MIMO case, but will be performed multiple times, once for each forward/reverse channel pair. For example, a MIMO system with 2 transmitters and 2 receivers in each transceiver is shown in FIGURE 2. This MIMO system has 4 forward/reverse channel pairs, so the calibration operation would be done 4 times, computing a total of 8 correction factors (4 at each transceiver).

FIGURE 3 diagrammatically illustrates exemplary embodiments of a transmit channel estimator apparatus according to the invention. The apparatus of FIGURE 3 can be provided in conjunction with, for example, any of the transceivers described above with respect to FIGURES 1 and 2. As shown in FIGURE 3, a channel estimation transmission received from another transceiver in another wireless communication station is input to a channel estimator 31. The channel estimator 31 can apply conventional techniques to the channel estimation transmission to produce a reverse channel estimate. This reverse channel estimate is input to a combiner 33. The combiner 33 combines the reverse channel estimate with a forward channel estimate received from the other transceiver to produce the correction factor, which can be stored in a storage device 35. The reverse channel estimate is also provided to the other transceiver, and will serve as the forward channel estimate input to the

combiner 33 in the transmit channel estimator of the other transceiver. When a current forward channel estimate is desired, for example at the time of a desired transmission, the most recent reverse channel estimate can be combined at 37 with the stored correction factor from storage device 35, thereby to produce the desired forward channel estimate for the transmitter.

FIGURE 4 illustrates exemplary operations which can be performed by cooperating transmit channel estimators provided in transceivers on opposite ends of the wireless communication links of FIGURES 1 and 2. At 41, the transceivers exchange channel estimation transmissions. At 43, each transmit channel estimator estimates its own reverse channel based on the channel estimation transmission that it received at 41. At 45, the transmit channel estimators exchange their respective reverse channel estimates with one another, thereby providing each other with forward channel estimates. At 47, each transmit channel estimator combines its own reverse channel estimate with the forward channel estimate that it received from the other transmit channel estimator, thereby to produce its correction factor.

Although exemplary embodiments of the invention are described above in detail, this does not limit the scope of the invention, which can be practiced in a variety of embodiments.